A modeling approach of Additive Manufacturing's learning based on Activity Theory

MOURAD ABOUELALA[1], MOHAMED OUBREK[1], MOURAD TAHA JANAN[1], PASCALE BRANDT-POMARES[2]

[1]*École Normale Supérieure de l'Enseignement Technique, Rabat*
Mohammed V University
Maroc
m.abouelala@um5s.net.ma

[2]*Aix-Marseille Université*
ENS Lyon, ADEF EA 4671, 13248, Marseille
France
Pascale.BRANDT-POMARES@univ-amu.fr

ABSTRACT

Implications 3D printing technology in the learning of new manufacturing technology and engineering are growing rapidly. 3D printing is a process of manufacturing solid objects and parts from a digital model without cutting tools and fixture systems. Although 3D printing is a powerful tool to empower learners through object creation, the need to put this learning in the context of education is necessary. This paper discusses how an Activity Theory model outlines and makes clearer the interactions student/ 3D printer learning in a global education context.

KEYWORDS

3D printing technology, Activity Theory, modeling's approach of Additive Manufacturing, fablabs

RÉSUMÉ

Les implications de l'impression 3D dans l'apprentissage des nouvelles technologies de fabrication et de l'ingénierie se développent rapidement. L'impression 3D est un procédé de fabrication d'objets solides et des pièces à partir d'un modèle numérique et ceci sans avoir recours aux outils de coupe ni aux systèmes de fixation. Bien que l'impression 3D soit un outil puissant pour l'habilitation des apprenants à travers la création d'objets, la nécessité de mettre cet apprentissage dans le contexte de l'éducation est nécessaire. Cet article explique comment le modèle de la théorie de l'activité présente et rend plus claire les interactions étudiant / apprentissage de l'impression 3D dans le contexte de l'éducation.

MOTS-CLÉS

Technologie de l'impression 3D, théorie de l'activité, modélisation de l'apprentissage de l'impression 3D, fablabs

INTRODUCTION

Companies are facing an increasingly uncertain industrial environment, in one hand the changes in the global competition, the expectations and needs of customers are becoming more specific, in second hand the rapid evolution of technology.

Civilizations were based on the forming of objects but claim for economic ecosystems that are improving the product accuracy, timeliness, reduction of equipment and material costs, development of new products and materials which had resulted in the emergence of flexible production methods such as additive manufacturing.

Additive Manufacturing (AM) is defined by American Society for Testing and Materials as 'the process of joining materials to make objects from 3D model data, usually layer upon layer' (ASTM 2012). AM has become an integral part of modern product development and the technology has been commercialized to the extent where machines are now affordable even for home use. Industrial applications are apparent in aerospace and automotive manufacturing, a wide range of medical applications and for the production of prototyping models for aesthetic and functional testing (Mark, Evans & Ian, 2003).

ADDITIVE MANUFACTURING PROCESS

AM can be described as a direct of streamlined computer Aided design to manufacturing process as illustrated by (figure 1 and figure 2).There is little intervention between the design and manufacturing stages compared to conventional CNC machining.

FIGURE 1   **FIGURE 2**
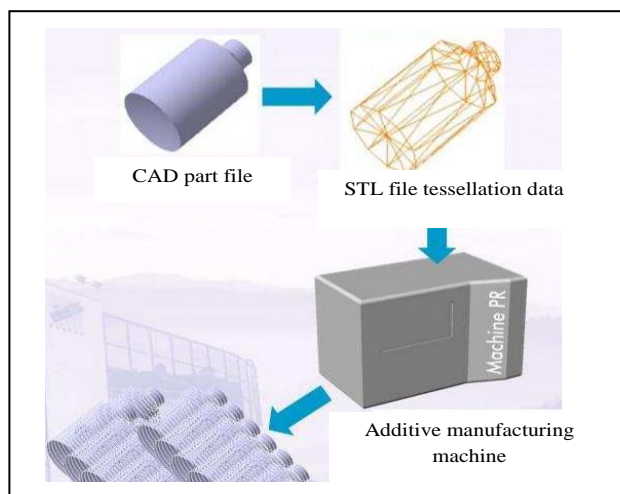
Stages of AM process   *AM's machine and computer control*

PROBLEMATIC OF AM's LEARNING

The conventional manufacturing is and will remain core to how many products are manufactured.

The approach of conventional manufacturing processes such as conventional CNC machining in education have standard theories of learning.

CNC machining learning in education is focused on processes where a subject acquires some identifiable knowledge or skills in such a way that a corresponding, relatively lasting change in the behaviour of the subject may be observed. It is a self-evident presupposition that the knowledge or skill to be acquired is itself stable and reasonably well defined. There is a competent 'teacher' who knows what is to be learned.

The problem is that some kinds of learning in education violate this presupposition. Students are some times learning something that is not stable, not even defined or understood ahead of time such as AM.

AM is new manufacturing process in education, the question is: What is the AM's efficient *learning model to be adopted* in education schools?

To achieve the full potential of AM, engineers' students must know how to design products for fabrication via AM. In addition, engineers students must not only understand AM technologies and materials, they must also be able to synthesize its economic and environmental impacts on a manufacturing value chain.

Design and manufacturing is considered to be the central or distinguishing activity of engineering (Wohlers, 2010). Research on engineering design thinking and learning has established that design is hard to learn and harder to teach (Simon, 1996).

How does learning occur? Cognitive theories stress the acquisition of knowledge and internal mental structures and, are, so, closer to the rationalist end of the epistemology continuum (Atman, Kilgore & McKenna, 2008). Learning is equated with discrete changes between states of knowledge rather than with changes in the probability of response. Knowledge acquisition is described as a mental activity that entails internal coding and structuring by the learner.

Instead, engineering design pedagogy follows the constructivist learning theory, in which it is postulated that students form knowledge representations of new information by building on their previous knowledge and experiences (Bower & Hilgard, 1981). If the new information has few connections to what they already know, learning will not occur, nor will students be motivated to learn (Pellegrino, 2006). Thus, effective instruction must provide experiences in which students actively construct knowledge by adjusting, rejecting, or modifying their prior beliefs and understanding based on their experiences (Albanese & Mitchell, 1993).

When students construct a new meaning, they may not believe it but may give it provisional acceptance or even rejection. Learning is an active process that depends on the students taking responsibility to learn.

The main activity in a constructivist classroom is solving problems. Students use inquiry methods to ask questions, investigate a topic, and use a variety of resources to find solutions and answers. As students explore the topic, they draw conclusions, and, as exploration continues, they revisit those conclusions. Exploration of questions leads to more questions.

There is a great deal of overlap between a constructivist and social constructivist classroom, with the exception of the greater emphasis placed on learning through social interaction, and the value placed on cultural background. For Vygotsky, culture gives the child the cognitive tools needed for development. Adults in the learner's environment are conduits for the tools of the culture, which include language, cultural history, social context, and more recently, electronic forms of information access.

In social constructivist classrooms collaborative learning is a process of peer interaction that is mediated and structured by the teacher. Discussion can be promoted by the presentation of

specific concepts, problems or scenarios, and is guided by means of effectively directed questions, the introduction and clarification of concepts and information and references to previously learned material.

Where a teacher and 2 to 4 students form a collaborative group and take turns leading dialogues on a topic. Within the dialogues, group members apply four cognitive strategies:

- Questioning
- Summarizing
- Clarifying
- Predicting

This creates a ZPD in which students gradually assume more responsibility for the material and through collaboration, forge group expectations for high-level thinking, and acquire vital skills for learning and success in everyday life.

The three theories cognitivism, constructivism and social constructivism can be adopted in an environment generally known technology and defined environment. The problem is that much of the most intriguing kinds of learning in work organizations violate this presupposition. People and organizations are all the time learning something that is not stable, not even defined or understood ahead of time.

As AM technology is recent manufacturing process, the learning environment in incessant evolution and changes this calls for a new learning approach such as expansive learning.

EXPANSIVE LEARNING AND ACTIVITY THEORY

A social learning model which has been expounded in a rather profound, dialectical, and some what philosophical way, is Yrjö Engeström's expansive learning theory (Engeström, 1987). Viewing psychology to be "at the limits of cognitivism", Engeström constructed a "coherent theoretical [instrument]" for grasping and bringing about processes where "circumstances are changed by men and the educator himself is educated".

Engeström voiced a rather strong view against a notion of learning "limited to processes of acquisition of skills, knowledge and behaviors, already mastered and codified by educational institutions", arguing that such a perspective makes learning irrelevant to the discovery and implementation of novel solutions:

If our notion of learning is limited to processes of acquisition of skills, knowledge, and behaviors already mastered and codified by educational institutions and other accepted representatives of cultural heritage, then finding and implementing future-oriented novel solutions to pressing societal problems has little to do with learning.

He proposed that a historically new form of learning, namely expansive learning of cultural patterns of activity that are not yet there, is emerging and needs to be understood.

The student as a member of a community living in a social environment, community is subjected to conditioning under the factors just mentioned, hence the need to take this into account, this is narrated through representation of Engström.

According to the activity theory ; the performance of students working on a AM process is conditioned by several factors including those relating to the student, the artifact that are the printer; the professor and organizational setting and environment which is the industrial companies.

FIGURE 3
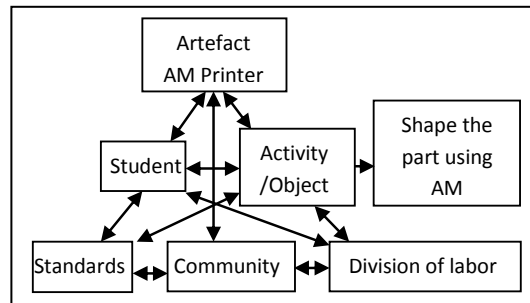
Schematization of the Student/AM printer interaction according to the activity theory due to Engström

Some of main relationships in this schematization are defined below.

The relationship between the student and the activity/object is mediated by the AM printer that is a technology tool and the tutorial. In this context, an activity represents a learning activity, which is broken down into actions and operations. The object represents the top level performance goal for the activity that is student's ability to perform part using AM technology.

The relationship between the student and the community that he is a part of it is mediated by a set of rules. Rules may encompass obligations, standards, regulations, and procedures.

The division of labor mediates the relationship between the community and the activity/object. The community may be either formally, who is teacher, or informally who is classmate. It is established depending upon the level of competencies needed to achieve the required performance outcome.

An implied relationship exists between the technology/tool and the community, and is mediated by the level of collaboration facilitated by the community. How does the level of collaboration within internally and externally situated communities (such us companies, AM developers, type of industry) of practice socially mediate the affect of technology?

An implied relationship exists between rules and the activity/object, and is mediated by the cultural setting and social context in which the activity occurs. How do different cultures and social settings (e.g., geographical separation and virtual teams) affect how rules are interpreted in activity-based performance?

An implied relationship between the division of labor and the student mediated by the student's perception affects his level of participation. How does this perception affect motivation to use AM technology for self-directed informal learning activities to achieve a performance outcome?

As activity systems are increasingly interconnected and interdependent, many recent studies of expansive learning take as their unit of analysis a constellation of two or more activity systems that have a partially shared object. Such interconnected activity systems may form a teacher–student relationship, a partnership, a network or another pattern of multi-activity collaboration.

The teacher's activity system is currently oriented at completing teaching strategies. The student's activity is oriented at learning and acquisition knowledge and competencies.

The two activity systems are intertwined in that they must act together to produce learning and competencies; yet their objects are different and there is increasing tension between them

(Figure 4). This state can be changed by means of an expansive learning process in which the two parties together generate a new shared object and concept for their shared activity.

FIGURE 4
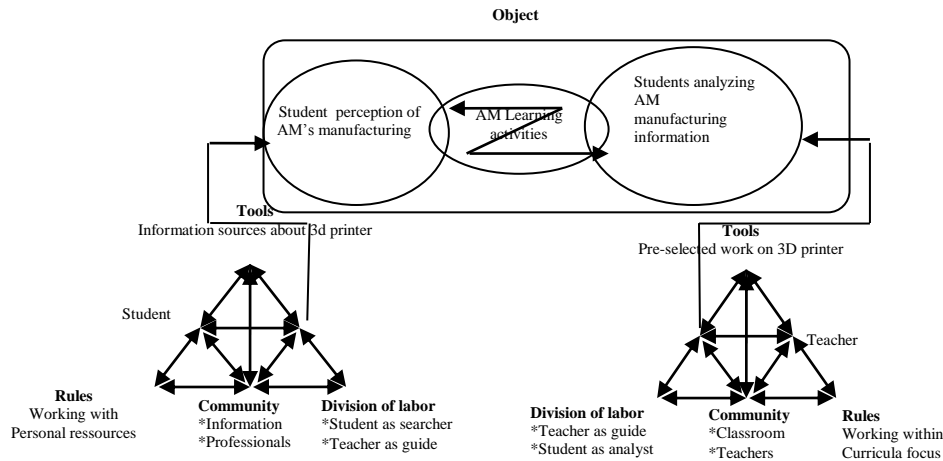
The interdependent activity systems of student and teacher

Contradictions are the necessary but not sufficient engine of expansive learning in an activity system. In different phases of the expansive learning process, contradictions may appear (a) as emerging latent primary contradictions within each and any of the nodes of the activity system, (b) as openly manifest secondary contradictions between two or more nodes, (c) as tertiary contradictions between a newly established mode of activity and remnants of the previous mode of activity, or (d) as external quaternary contradictions between the newly reorganized activity and its neighboring activity systems.

Conflicts, dilemmas, disturbances and local innovations may be analyzed as manifestations of the contradictions. There is a substantial difference between conflict experiences and developmentally significant contradictions. The first are situated at the level of short-time action, the second are situated at the level of activity and inter-activity, and have a much longer life cycle. They are located at two different levels of analysis. The roots of conflicts can be explored by shifting from the action level of conflict to the activity level of contradiction (Sannino, 2005).

Contradictions become actual driving forces of expansive learning when they are dealt with in such away that an emerging new object is identified and turned into a motive: "the meeting of need with object is an extraordinary act" (Leont'ev, 1978).

RESEARCH METHODS

The AM enables new forms of teaching and learning and demands major shifts in teachers' professional practice. Thus professional development needs to be redirected from refining established practice (Higgins, Beauchamp & Miller, 2007) towards pervasively transforming practice (Mishra & Koehler, 2006). A transformed teaching practice requires comprehensive learning towards the notion of expansive learning (Engeström, 2001).

In expansive learning the subject of learning is transformed from an individual to a collective or a network of activity systems.

Originally directed at learning in the workplace that is in our case 3D practical workshop, and how learning at work produces new forms of work activity, this theory keeps a sharp focus on learning and systemic modification and adaptation. It is a theory of learning that demonstrates how and why prior knowledge is transformed through a cyclical sequence into new, internalized, and transferable knowledge. New and pre-existing knowledge is synthesized to create new knowledge that can lead to improvements and modifications of knowledge and social practice. (*Two aspects for teacher: teaching methods and project difficulties; for students: learning new manufacturing technology such as AM manufacturing and project difficulties*)

Expansive learning is a cycle or spiral of learning that commences with questioning. The cycle then moves through a sequence of analysis: the double bind becomes apparent; the new solution or breakthrough is modelled; trial (*examining and testing the new model*) and evaluation of an adjusted model take place; and, through adjustment and enrichment, this new model is implemented. This is followed by reflection on the process and finally the consolidation of new practice and the extrapolation of this to generalization of this learning.

This cycle is not unidirectional, but rather that movement occurs "back and forth between the different actions". Nor is this cycle immune from disruption, partial or complete.

To implement the research method, we will report from a sample of engineering schools and universities innovative AM projects, where students or group of students and their teachers collaborate in new situations to achieve of new works.

The sample size must be significant for the research, while there is no steadfast rule; there are a number of well-researched approaches Rule of 500. Comrey and Lee (1992) thought if sample size is 100 = poor, 200 = fair, 300 = good, 500 = very good, 1,000 or more = excellent They urged researchers to obtain samples of 500 or more observations whenever possible (in MacCallum, Widaman, Zhang & Hong, 1999, p. 84).

TREATMENT STAGES AND EXPECTED RESULTS

The research design includes four stages and employs primary methods of semi-structured interviews and surveys, including both students and teachers.

The investigation will involve 300 students' engineering schools and universities and 300 teachers. A variety of data such as; hands-on workshop observations, practical productions, interviews and content analysis of teachers' planning and reflection notes provides the basis for our analysis along with activity theory as an analytical framework.

Stage one involved exploratory work during new AM projects, where students or group of students and teachers collaborate in new situations to achieve of new works. This period will enable us to develop the scope and direction of an appreciative inquiry into participant experiences, while also reflexively considering the pedagogical outcomes of the program.

Stage two we will synthesize a literature review with preliminary participant observation data to further develop students' and teachers' questionnaire.

Stage three involved data collection and designing the questionnaire about (who are learning; why do they learn; what do they learn and how do they learn) to a sample of students and to teachers about (who are teaching; why do they teach; what do they teach and how do they teach), then submitting questionnaire to students and teachers.

Stage four concerns the third strategic action in expansive learning that is modeling. Modeling is already involved in the formulation of the framework and results of the *analysis of contradictions deduced from the analysis of previous questionnaires*, and it reaches its end result in the modeling of the new solution, the new instrumentality, the new pattern of AM learning activity.

CONCLUSION: POTENTIAL AND OPPORTUNITIES FOR USE OF AM IN EDUCATION

By expansive learning we mean the capacity of engineers' students to interpret and expand the definition of the object of new manufacturing technology learning and respond to it in increasingly enriched ways.

This paper present Additive Manufacturing learning pedagogy that follows the constructivist and socio constructivist learning models, and propose another approach based on expansive learning. This approach may provide to students new opportunities for action and interest in engineering education domain.

AM reflects the effectiveness expected from the use of the new digital tool in terms of the teaching-learning of manufacturing process. It is a potential tool to be efficient in the manufacturing teaching and learning process which is important for technical universities.

From the interviews with students, fablab users, teachers and observing the students and fablab users engaged in AM's activities we will be able to understand the different perspectives of AM's learning.

In an other perspectives of this research, we plan to conduct a project-based learning with a first sample of students from technical universities and a free work chosen by learners of a second sample from Fablabs using 3D printers to compare the effects of two strategies on the effectiveness of the AM's learning process.

REFERENCES

Albanese, M. A., & Mitchell, S. (1993). Problem-Based Learning: a review of literature on its outcomes and implementation issues. *Academic Medicine*, *68*, 52-81.

ASTM (2012). ASTM F279210 Standard Terminology for Additive Manufacturing Technologies. American Society for Testing and Materials (ASTM). Retrieved from http://www.astm.org/DATABASE.CART/HISTORICAL/F279210. htm.G.

Atman, C., Kilgore, D., & McKenna, A. (2008). Characterizing Design Learning: a mixed-methods study of engineering designers' use of language. *Journal of Engineering Education, 97*(3)*,* 309-326*.*

Bower, G. H., & Hilgard, E. R. (1981). *Theories of learning*. Englewood Cliffs, NJ: Prentice-Hall.

Engeström, Y. (1987). *Learning by expanding: an activity: theoretical approach to development research*. Helsinki: Orienta-Konsultit.

Engeström, Y. (2001). Expansive learning at work: toward an activity theoretical reconceptualization. *Journal of Education and Work*, *14*(1), 133-156.

Higgins, S., Beauchamp, G., & Miller, D. (2007). Reviewing the literature on interactive whiteboards. *Learning, Media and Technology*, *32*(3), 213-225.

Leont'ev, A. N. (1978). *Activity, consciousness and personality*. Englewood Cliffs: Prentice-Hall.

MacCallum, R. C., Widaman, K. F., Zhang, S., & Hong, S. (1999). Sample size in factor analysis. *Psychological Methods*, *4*, 84-99.

Mark, A., Evans, R., & Ian, C. (2003). A comparative evaluation of industrial design models produced using rapid prototyping and workshop based fabrication techniques. *Rapid Prototyping Journal, 9*(*05*), 344-351.

Mishra, P., & Koehler, M. J. (2006). Technological pedagogical content knowledge: a framework for teacher knowledge. *Teachers College Record*, *108*(6), 1017-1054.

Pellegrino, J. W. (2006). *Rethinking and redesigning curriculum, instruction and assessment: What contemporary research and theory suggests*. USA: National Center on Education and the Economy for the New Commission on the Skills of the American Workforce.

Sannino, A. (2005). Cultural-historical and discursive tools for analyzing critical conflicts in students' development. In K. Yamazumi, Y. Engeström & H. Daniels (Eds.), *New learning challenges: Going beyond the industrial age system of school and work* (pp. 165-195). Osaka: Kansai University Press.

Simon, H. A. (1996). *The Sciences of the Artificial*. Cambridge, MA: MIT Press.

Wohlers, T., (2010) *Wohlers Report 2010: Additive Manufacturing state of the industry annual worldwide progress report*. Fort Collins, Colorado: Wohlers Associates, Inc.